Chapter Five
Weathering and Soils
Earth’s External Processes

Weathering and Soil External versus Internal Processes:

Weathering, mass wasting, and erosion are called external processes because they occur at or near Earth's surface and are powered by energy from the Sun. External processes are a basic part of the rock cycle because they are responsible for transforming solid rock into sediment.

To the casual observer, the face of Earth may appear to be without change, unaffected by time. In fact, 200 years ago, most people believed that mountains, lakes, and deserts were permanent features of an Earth that was thought to be no more than a few thousand years old. Today we know that Earth is 4.6 billion years old and that mountains eventually give way to weathering and erosion, lakes fill with sediment or are drained by streams, and deserts come and go with changes in climate.

Earth is a dynamic body. Some parts of Earth’s surface are gradually elevated by mountain building and volcanic activity. These internal processes derive their energy from Earth’s interior. Meanwhile, opposing external processes are continually breaking rock apart and moving the debris to lower elevations. The latter processes include:

1. Weathering—the physical breakdown (disintegration) and chemical alteration (decomposition) of rocks at or near Earth’s surface.
2. Mass wasting—the transfer of rock and soil downslope under the influence of gravity.
3. Erosion—the physical removal of material by mobile agents such as water, wind, or ice.

In this chapter we will focus on rock weathering and the products generated by this activity. However, weathering cannot be easily separated from mass wasting and erosion, because as weathering breaks rocks apart, mass wasting and erosion remove the rock debris. This transport of material by mass wasting and erosion further disintegrates and decomposes the rock.

Weathering

Weathering and Soil Types of Weathering

Weathering goes on all around us, but it seems like such a slow and delicate process that it is easy to underestimate its importance. It is worth remembering that weathering is a basic part of the rock cycle and thus a key process in the Earth system.

Weathering is also important to humans—even to those of us who are not studying geology. For example, many of the life-sustaining minerals and elements found in soil, and ultimately in the food we eat, were freed from solid rock by weathering processes. As the chapter-opening photo, and many other images in this book illustrate, weathering also contributes to the formation of some of Earth’s most spectacular views. Of course, these same processes are also responsible for causing the deterioration of many of the structures we build.

All materials are susceptible to weathering. Consider, for example, the fabricated product concrete, which closely resembles the sedimentary rock called conglomerate. A newly poured concrete sidewalk has a smooth, fresh, unweathered look. However, not many years later, the same sidewalk will appear chipped, cracked, and rough, with pebbles exposed at the surface. If a tree is nearby, its roots may heave and buckle the concrete as well. The same natural processes that eventually break apart a concrete sidewalk act to disintegrate rock.

Weathering occurs when rock is mechanically fragmented (disintegrated) and/or chemically altered (decomposed). Mechanical weathering is accomplished by physical forces that break rock into smaller and smaller pieces without changing the rock’s mineral composition. Chemical weathering involves a chemical transformation of rock into one or more new compounds. These two concepts can be illustrated with a piece of paper. The paper can be
disintegrated by tearing it into smaller and smaller pieces, whereas decomposition occurs when the paper is set afire and burned.

Why does rock weather? Simply, weathering is the response of Earth materials to a changing environment. For instance, after millions of years of uplift and erosion, the rocks overlying a large intrusive igneous body may be removed, exposing it at the surface. The mass of crystalline rock, which formed deep below ground where temperatures and pressures are much greater than at the surface, is now subjected to a very different and comparatively hostile surface environment. In response, this rock mass will gradually change. This transformation of rock is what we call weathering.

In the following sections, we will discuss the various modes of mechanical and chemical weathering. Although we will consider these two categories separately, keep in mind that mechanical and chemical weathering processes usually work simultaneously in nature and reinforce each other.

**Mechanical Weathering**

**Weathering and Soil Mechanical Weathering**

When a rock undergoes mechanical weathering, it is broken into smaller and smaller pieces, each retaining the characteristics of the original material. The end result is many small pieces from a single large one. By breaking a rock into smaller pieces, it increases the surface area available for chemical attack. An analogous situation occurs when sugar is added to a liquid. In this situation, a cube of sugar will dissolve much more slowly than an equal volume of sugar granules because the cube has much less surface area available for dissolution. Hence, by breaking rocks into smaller pieces, mechanical weathering increases the amount of surface area available for chemical weathering.

In nature, four physical processes are especially important in breaking rocks into smaller fragments: frost wedging, salt crystal growth, expansion resulting from unloading, and biological activity. In addition, although the work of erosional agents such as wind, glacial ice, rivers, and waves is usually considered separately from mechanical weathering, it is nevertheless important to point out that as these mobile agents move rock debris, they relentlessly disintegrate these materials.

**Frost Wedging**

If you leave a glass bottle of water in the freezer a bit too long, you will find the bottle fractured. The bottle breaks because water has the unique property of expanding about 9 percent upon freezing. This is also the reason that poorly insulated or exposed water pipes rupture during frigid weather. You might expect this same process to fracture rocks in nature.

This is, in fact, the basis for the traditional explanation of frost wedging. After water works its way into the cracks in rock, the freezing water enlarges the cracks and angular fragments are eventually produced. For many years, the conventional wisdom was that most frost wedging occurred in this way. Recently, however, research has shown that frost wedging can also occur in a different way. It has long been known that when moist soils freeze, they expand or frost heave due to the growth of ice lenses. These masses of ice grow larger because they are supplied with water migrating from unfrozen areas as thin liquid films. As more water accumulates and freezes, the soil is heaved upward. A similar process occurs within the cracks and pore spaces of rocks. Lenses of ice grow larger as they attract liquid water from surrounding pores. The growth of these ice masses gradually weakens the rock, causing it to fracture.

**Salt Crystal Growth**

Another expansive force that can split rocks is created by the growth of salt crystals. Rocky shorelines and arid regions are common settings for this process. It begins when sea spray from breaking waves or salty groundwater penetrates crevices and pore spaces in
rock. As this water evaporates, salt crystals form. As these crystals gradually grow larger, they weaken the rock by pushing apart the surrounding grains or enlarging tiny cracks. This same process can contribute to crumbling roadways where salt is spread to melt snow and ice in winter. The salt dissolves in water and seeps into cracks that quite likely originated from frost action. When the water evaporates, the growth of salt crystals further breaks the pavement.

**Sheeting:**
When large masses of igneous rock, particularly granite, are exposed by erosion, concentric slabs begin to break loose. The process generating these onion like layers is called sheeting. It is thought that this occurs, at least in part, because of the great reduction in pressure when the overlying rock is eroded away, a process called unloading. Accompanying this unloading, the outer layers expand more than the rock below and thus separate from the rock body (FIGURE 5.5). Continued weathering eventually causes the slabs to separate and spall off, creating exfoliation domes. Excellent examples of exfoliation domes include Stone Mountain, Georgia, and Half Dome (Figure 5.5C), and Liberty Cap in Yosemite National Park. Deep underground mining provides us with another example of how rocks behave once the confining pressure is removed. Large rock slabs sometimes explode off the walls of newly cut mine tunnels because of the abruptly reduced pressure. Evidence of this type, plus the fact that fracturing occurs parallel to the floor of a quarry when large blocks of rock are removed, strongly supports the process of unloading as the cause of sheeting. Although many fractures are created by expansion, others are produced by contraction as igneous materials cool (see Figure 4.31, p. 112), and still others by tectonic forces during mountain building. Fractures produced by these activities often form a definite pattern and are called joints (FIGURE 5.6). Joints are important rock structures that allow water to penetrate deeply and start the process of weathering long before the rock is exposed.

**Biological Activity**
Both mechanical and chemical weathering are accomplished by the activities of organisms. Plant roots in search of minerals and water grow into fractures, and as the roots grow, they wedge the rock apart (FIGURE 5.7). Burrowing animals further break down the rock by moving fresh material to the surface, where physical and chemical processes can more effectively attack it. Of course, where rock has been blasted in search of minerals or for construction, the impact of humans is particularly noticeable. There are numerous ways that organisms play a role in chemical weathering. For example, some bacteria are capable of extracting compounds from minerals and using the energy from the compound’s chemical bonds to supply their life needs. These primitive “mineral-eating” life forms can live at depths as great as a few kilometers.

**Chemical Weathering**
Weathering and Soil Chemical Weathering
In the preceding discussion of mechanical weathering you learned that breaking rock into smaller pieces aids chemical weathering by increasing the surface area available for chemical attack. It should also be pointed out that chemical weathering contributes to mechanical weathering. It does so by weakening the outer portions of some rocks which, in turn, makes them more susceptible to being broken by mechanical weathering processes. Chemical weathering involves the complex processes that break down rock components
and internal structures of minerals. Such processes convert the constituents to new minerals or release them to the surrounding environment. During this transformation, the original rock decomposes into substances that are stable in the surface environment. Consequently, the products of chemical weathering will remain essentially unchanged as long as they remain in an environment similar to the one in which they formed.

**Water and Carbonic Acid:**

Water is by far the most important agent of chemical weathering. Although pure water is nonreactive, a small amount of dissolved material is generally all that is needed to activate it. Oxygen dissolved in water will oxidize some materials. For example, when an iron nail is found in moist soil, it will have a coating of rust (iron oxide), and if the time of exposure has been long, the nail will be so weak that it can be broken as easily as a toothpick. When rocks containing iron-rich minerals oxidize, a yellow to reddish-brown rust will appear on the surface.

Carbon dioxide (CO₂) dissolved in water (H₂O) forms carbonic acid (H₂CO₃), the same weak acid produced when soft drinks are carbonated. Rain dissolves some carbon dioxide as it falls through the atmosphere, and additional amounts released by decaying organic matter are acquired as the water percolates through the soil. Carbonic acid ionizes to form the very reactive hydrogen ion (H⁺) and the bicarbonate ion (HCO₃⁻). Acids such as carbonic acid readily decompose many rocks and produce certain products that are water soluble.

For example, the mineral calcite (CaCO₃), which composes the common building stones marble and limestone, is easily attacked by even a weakly acidic solution. The most abundant products of the chemical breakdown of feldspar are residual clay minerals. Clay minerals are the end products of weathering and are very stable under surface conditions. Consequently, clay minerals make up a high percentage of the inorganic material in soils. Moreover, the most abundant sedimentary rock, shale, contains a high proportion of clay minerals.

In addition to the formation of clay minerals during the weathering of feldspar, some silica is removed from the feldspar structure and is carried away by groundwater (water beneath Earth’s surface). This dissolved silica will eventually precipitate to produce nodules of chert or flint, or it will fill in the pore spaces between sediment grains, or it will be carried to the ocean, where microscopic animals will remove it from the water to build hard silica shells.

Quartz, the other main component of granite, is very resistant to chemical weathering; it remains substantially unaltered when attacked by weak acidic solutions. As a result, when granite weathers, the feldspar crystals slowly turn to clay, releasing the once-interlocked quartz grains, which still retain their fresh, glassy appearance. Although some quartz remains in the soil, much is eventually transported to the sea or to other sites of deposition, where it becomes the main constituent of such features as sandy beaches and sand dunes. In time these quartz grains may become a sedimentary rock (sandstone).

**Weathering of Silicate Minerals**

Table 5.1 lists the weathered products of some of the most common silicate minerals. Remember that silicate minerals make up most of Earth’s crust and that these minerals are composed essentially of only eight elements. When chemically weathered, silicate minerals yield sodium, calcium, potassium, and magnesium ions that form soluble products, which may be removed by groundwater. The element iron combines with oxygen, producing relatively insoluble iron oxides, which give soil a reddish-brown or yellowish color. Under most conditions the three remaining elements—aluminum, silicon, and oxygen—join with
water to produce residual clay minerals. However, even the highly insoluble clay minerals are very slowly removed by subsurface water.

**Spheroidal Weathering**

In addition to altering the internal structure of minerals, chemical weathering causes physical changes. *For instance, when angular rock masses chemically weather as water enters along joints, they tend to take on a spherical shape. Gradually the corners and edges of the angular blocks become more rounded. The corners are attacked most readily because of their greater surface area, as compared to the edges and faces. This process, called spheroidal weathering, gives the weathered rock a more rounded or spherical shape.* Sometimes during the formation of spheroidal boulders, successive shells separate from the rock’s main body. Eventually the outer shells break off, allowing the chemical-weathering activity to penetrate deeper into the boulder.

**Rates of Weathering**

*Several factors influence the type and rate of rock weathering. We have already seen how mechanical weathering affects the rate of weathering. By breaking rock into smaller pieces, the amount of surface area exposed to chemical weathering is increased. Other important factors examined here include rock characteristics and climate.*

**Rock Characteristics**

Rock characteristics encompass all of the chemical behaviors of rocks, including mineral composition and solubility. In addition, any physical features such as joints (cracks) can be important because they allow water to penetrate rock and start the process of weathering long before the rock is exposed.

The variations in weathering rates due to the mineral constituents can be demonstrated by comparing old headstones made from different rock types. Headstones of granite, which are composed of silicate minerals, are relatively resistant to chemical weathering. In contrast to the granite, the marble headstone shows signs of extensive chemical alteration over a relatively short period of time. Marble is composed of calcite (calcium carbonate), which readily dissolves even in a weakly acidic solution.

The silicates, the most abundant mineral group, weather in essentially the same order as their order of crystallization. By examining Bowen’s reaction series, you can see that olivine crystallizes first and is therefore the least resistant to chemical weathering, whereas quartz, which crystallizes last, is the most resistant.

**Climate**

Climatic factors, particularly temperature and moisture, are crucial to the rate of rock weathering. One important example from mechanical weathering is that the frequency of freeze–thaw cycles greatly affects the amount of frost wedging.

Temperature and moisture also exert a strong influence on rates of chemical weathering and on the kind and amount of vegetation present. Regions with lush vegetation generally have a thick mantle of soil rich in decayed organic matter from which chemically active fluids such as carbonic acids are derived.

The optimal environment for chemical weathering is a combination of warm temperatures and abundant moisture. In polar regions chemical weathering is ineffective because frigid temperatures keep the available moisture locked up as ice, whereas in arid regions there is insufficient moisture to foster rapid chemical weathering.

Human activities can influence the composition of the atmosphere, which in turn can impact the rate of chemical weathering. One well-known example is acid rain.
Soil covers most land surfaces. Along with air and water, it is one of our most indispensable resources. Also, like air and water, soil is taken for granted by many of us. The following quote helps put this vital layer in perspective.

*Science, in recent years, has focused more and more on the Earth as a planet, one that for all we know is unique—where a thin blanket of air, a thinner film of water, and the thinnest covering of soil combine to support a web of life of wondrous diversity in continuous change.*

Soil has accurately been called “the bridge between life and the lifeless world.” All life—the entire biosphere—owes its existence to a dozen or so elements that must ultimately come from Earth’s crust. Once weathering and other processes create soil, plants carry out the intermediary role of adapting the necessary elements and making them available to animals, including humans.

An Interface in the Earth System

When Earth is viewed as a system, soil is referred to as an interface—a common boundary where different parts of a system interact. This is an appropriate designation because soil forms where the geosphere, the atmosphere, the hydrosphere, and the biosphere meet. Soil is a material that develops in response to complex environmental interactions among different parts of the Earth system. Over time, soil gradually evolves to a state of equilibrium or balance with the environment. Soil is dynamic and sensitive to almost every aspect of its surroundings.

Thus, when environmental changes occur, in climate, vegetative cover, or animal (including human) activity, the soil responds. Any such change produces a gradual alteration of soil characteristics until a new balance is reached. Although thinly distributed over the land surface, soil functions as a fundamental interface, providing an excellent example of the integration among many parts of the Earth system.

What Is Soil?

With few exceptions, Earth’s land surface is covered by layers of rock and mineral fragments produced by weathering. Some would call this material soil, but soil is more than an accumulation of weathered debris. Soil is a combination of mineral and organic matter, water, and air.

Although the proportions of the major components in soil vary, the same four components always are present to some extent. About one-half of the total volume of a good quality surface soil is a mixture of disintegrated and decomposed rock (mineral matter) and humus, the decayed remains of animal and plant life (organic matter). The remaining half consists of pore spaces among the solid particles where air and water circulate.

Although the mineral portion of the soil is usually much greater than the organic portion. In addition to being an important source of plant nutrients, humus enhances the soil’s ability to retain water.

Because plants require air and water to live and grow, the portion of the soil consisting of pore spaces that allow for the circulation of these fluids is as vital as the solid soil constituents.

Soil water is far from “pure” water; instead, it is a complex solution containing many soluble nutrients. Soil water not only provides the necessary moisture for the chemical reactions that sustain life, it also supplies plants with nutrients in a form they can use. The pore spaces that are not filled with water contain air. This air is the source of necessary oxygen and carbon dioxide for most microorganisms and plants that live in the soil.
Controls of Soil Formation

Soil is the product of the complex interplay of several factors. The most important of these are parent material, time, climate, plants and animals, and topography. Although all of these factors are interdependent, their roles will be examined separately.

Parent Material

The source of the weathered mineral matter from which soils develop is called the parent material and is a major factor influencing a newly forming soil. Gradually it undergoes physical and chemical changes as the processes of soil formation progress. Parent material might be the underlying bedrock, or it can be a layer of unconsolidated deposits, as in a stream valley. When the parent material is bedrock, the soils are termed residual soils. By contrast, those developed on unconsolidated sediment are called transported soils. Note that transported soils form in place on parent materials that have been carried from elsewhere and deposited by gravity, water, wind, or ice.

The nature of the parent material influences soils in two ways. First, the type of parent material affects the rate of weathering and thus the rate of soil formation. Also, because unconsolidated deposits are already partly weathered and provide more surface area for chemical weathering, soil development on such material usually progresses more rapidly. Second, the chemical make-up of the parent material affects the soil’s fertility. This influences the character of the natural vegetation the soil can support.

At one time the parent material was thought to be the primary factor causing differences among soils. However, soil scientists came to understand that other factors, especially climate, are more important. In fact, it was found that similar soils often develop from different parent materials and that dissimilar soils develop from the same parent material. Such discoveries reinforce the importance of the other soil forming factors.

Time

Time is an important component of every geological process, and soil formation is no exception. The nature of soil is strongly influenced by the length of time that processes have been operating. If weathering has been going on for a comparatively short time, the parent material strongly influences the characteristics of the soil. As weathering processes continue, the influence of parent material on soil is overshadowed by the other soil-forming factors, especially climate. The amount of time required for various soils to evolve cannot be specified, because the soil-forming processes act at varying rates under different circumstances. However, as a rule, the longer a soil has been forming, the thicker it becomes and the less it resembles the parent materials.

Climate

Climate is the most influential control of soil formation. Just as temperature and precipitation are the climatic elements that influence people the most, so too are they the elements that exert the strongest impact on soil formation. Variations in temperature and precipitation determine whether chemical or mechanical weathering predominates. They also greatly influence the rate and depth of weathering. For instance, a hot, wet climate may produce a thick layer of chemically weathered soil in the same amount of time that a cold, dry climate produces a thin mantle of mechanically weathered debris. Also, the amount of precipitation influences the degree to which various materials are removed (leached) from the soil, thereby affecting soil fertility. Finally, climatic conditions are important factors controlling the type of plant and animal life present.
Plants and Animals

The biosphere plays a vital role in soil formation. The types and abundance of organisms present have a strong influence on the physical and chemical properties of a soil. In fact, for well-developed soils in many regions, the significance of natural vegetation in influencing soil type is frequently implied in the description used by soil scientists. Such phrases as plain soil, forest soil, and tundra soil are common.

Plants and animals furnish organic matter to the soil. Certain swamp soils are composed almost entirely of organic matter, whereas desert soils may contain only a tiny percentage. Although the quantity of organic matter varies substantially among soils, it is the rare soil that completely lacks it.

The primary source of organic matter is plants, although animals and the uncountable microorganisms also contribute. When organic matter decomposes, important nutrients are supplied to plants, as well as to animals and microorganisms living in the soil. Consequently, soil fertility depends in part on the amount of organic matter present.

Furthermore, the decay of plant and animal remains causes the formation of various organic acids. These complex acids hasten the weathering process. Organic matter also has a high water-holding ability and thus aids water retention in a soil.

Microorganisms, including fungi and bacteria, play an active role in the decay of plant and animal remains. The end product is humus, a material that no longer resembles the plants and animals from which it was formed. In addition, certain microorganisms aid soil fertility because they have the ability to convert atmospheric nitrogen into soil nitrogen.

Earthworms and other burrowing animals act to mix the mineral and organic portions of a soil. Earthworms, for example, feed on organic matter and thoroughly mix soils in which they live, often moving and enriching many tons per acre each year. Burrows and holes also aid the passage of water and air through the soil.

Topography

The lay of the land can vary greatly over short distances. Such variations in topography can lead to the development of a variety of localized soil types. Many of the differences exist because the length and steepness of slopes have a significant impact on the amount of erosion and the water content of soil.

On steep slopes, soils are often poorly developed. In such situations little water can soak in; as a result, soil moisture may be insufficient for vigorous plant growth.

Further, because of accelerated erosion on steep slopes, the soils are thin or nonexistent. In contrast, waterlogged soils in poorly drained bottom lands have a much different character. Such soils are usually thick and dark. The dark color results from the large quantity of organic matter that accumulates because saturated conditions retard the decay of vegetation. The optimum terrain for soil development is a flat-to-undulating upland surface. Here we find good drainage, minimum erosion, and sufficient infiltration of water into the soil.

Slope orientation, or the direction a slope is facing, also is significant. In the mid latitudes of the Northern Hemisphere, a south-facing slope receives a great deal more sunlight than a north-facing slope. In fact, a steep north-facing slope may receive no direct sunlight at all.

The difference in the amount of solar radiation received causes substantial differences in soil temperature and moisture, which in turn influence the nature of the vegetation and the character of the soil.

Although we have dealt separately with each of the soil-forming factors, remember that all of them work together to form soil. No single factor is responsible for a soil’s character. Rather, it is the combined influence of parent material, time, climate, plants and animals, and topography that determines this character.
The Soil Profile

Because soil-forming processes operate from the surface downward, variations in composition, texture, structure, and color gradually evolve at varying depths. These vertical differences, which usually become more pronounced as time passes, divide the soil into zones or layers known as horizons. If you were to dig a trench in soil, you would see that its walls are layered. Such a vertical section through all of the soil horizons constitutes the soil profile (FIGURE 5.17). FIGURE 5.18 presents an idealized view of a well-developed soil profile in which five horizons are identified. From the surface downward, they are designated as O, A, E, B, and C, respectively. These five horizons are common to soils in temperate regions. The characteristics and extent of development of horizons vary in different environments. Thus, different localities exhibit soil profiles that can contrast greatly with one another.

The O horizon consists largely of organic material. This is in contrast to the layers beneath it that consist mainly of mineral matter. The upper portion of the O horizon is primarily plant litter such as loose leaves and other organic debris that are still recognizable. By contrast, the lower portion of the O horizon is made up of partly decomposed organic matter (humus) in which plant structures can no longer be identified. In addition to plants, the O horizon is teeming with microscopic life, including bacteria, fungi, algae, and insects. All of these organisms contribute oxygen, carbon dioxide, and organic acids to the developing soil.

Underlying the organic-rich O horizon is the A horizon. This zone is largely mineral matter, yet biological activity is high and humus is generally present. Together the O and A horizons make up what is commonly called topsoil. Below the A horizon, the E horizon is a light-colored layer that contains little organic material. As water percolates downward through this zone, finer particles are carried away. This washing out of the fine soil components is termed eluviation. Water percolating downward also dissolves soluble inorganic soil components and carries them to deeper zones. This depletion of soluble materials from the upper soil is termed leaching.

Immediately below the E horizon is the B horizon, or subsoil. Much of the material removed from the E horizon by eluviation is deposited in the B horizon, which is often referred to as the zone of accumulation. The accumulation of the fine clay particles enhances water retention in the subsoil. However, in extreme cases clay accumulation can form a very compact and impermeable layer called hardpan. The O, A, E, and B horizons together constitute the solum, or true soil. It is in the solum that the soil-forming processes are active and that living roots and other plant and animal life are largely confined.

Below the solum and above the unaltered parent material is the C horizon, a layer characterized by partially altered parent material. Whereas the O, A, E, and B horizons bear little resemblance to the parent material, it is easily identifiable in the C horizon. Although this material is undergoing changes that will eventually transform it into soil, it has not yet crossed the threshold that separates regolith from soil.

The characteristics and extent of development can vary greatly among soils in different environments. The boundaries between soil horizons may be very distinct, or the horizons may blend gradually from one to another. A well-developed soil profile indicates that environmental conditions have been relatively stable over an extended time span and that the soil is mature. By contrast, some soils lack horizons altogether. Such soils are called immature, because soil building has been going on for only a short time. Immature soils are also characteristic of steep slopes where erosion continually strips away the soil, preventing full development.

Classifying Soils

There are many variations from place to place and from time to time among the factors that control soil formation. These differences lead to a puzzling variety of soil types. To cope with such variety, it is essential to devise some means of classifying the vast array of data.
to be studied. By establishing groups consisting of items that have certain important characteristics in common, order and simplicity are introduced. Bringing order to large quantities of information not only aids comprehension and understanding but also facilitates analysis and explanation.

In the United States, soil scientists have devised a system for classifying soils known as the Soil Taxonomy. It emphasizes the physical and chemical properties of the soil profile and is organized on the basis of observable soil characteristics. There are six hierarchical categories of classification, ranging from order, the broadest category, to series, the most specific category. The system recognizes 12 soil orders and more than 19,000 soil series. The names of the classification units are combinations of syllables, most of which are derived from Latin or Greek.

Clearing the Tropical Rain Forest—A Case Study of Human Impact on Soil

Thick red soils are common in the wet tropics and subtropics. They are the end product of extreme chemical weathering. Because lush tropical rain forests are associated with these soils, we might assume they are fertile and have great potential for agriculture. However, just the opposite is true—they are among the poorest soils for farming. How can this be?

Because rain forest soils develop under conditions of high temperature and heavy rainfall, they are severely leached. Not only does leaching remove the soluble materials such as calcium carbonate, but the great quantities of percolating water also remove much of the silica, with the result that insoluble oxides of iron and aluminum become concentrated in the soil. Iron oxides give the soil its distinctive red color. Because bacterial activity is very high in the tropics, rain forest soils contain practically no humus. Moreover, leaching destroys fertility because most plant nutrients are removed by the large volume of downward-percolating water. Therefore, even though the vegetation may be dense and flourishing, the soil itself contains few available nutrients.

Most nutrients that support the rain forest are locked up in the trees themselves. As vegetation dies and decomposes, the roots of the rain forest trees quickly absorb the nutrients before they are leached from the soil. The nutrients are continuously recycled as trees die and decompose.

Therefore, when forests are cleared to provide land for farming or to harvest the timber, most of the nutrients are removed as well. What remains is a soil that contains little to nourish planted crops. The clearing of rain forests not only removes plant nutrients but also accelerates erosion. When vegetation is present, its roots anchor the soil, and its leaves and branches provide a cover that protects the ground by deflecting the full force of the frequent heavy rains.

The removal of vegetation also exposes the ground to strong direct sunlight. When baked by the Sun, these tropical soils can harden to a bricklike consistency and become practically impenetrable to water and crop roots. In only a few years, soils in a freshly cleared area may no longer be cultivable.

The term laterite, which is often applied to these soils, is derived from the Latin word laterie, meaning “brick,” and was first applied to the use of this material for brick-making in India and Cambodia. Laborers simply excavated the soil, shaped it, and allowed it to harden in the Sun. Ancient but still well-preserved structures built of laterite remain standing today in the wet tropics (FIGURE 5.21). Such structures have withstood centuries of weathering because all of the original soluble materials were already removed from the soil by chemical weathering.
Laterites are therefore virtually insoluble and very stable. In summary, we have seen that some rain forest soils are highly leached products of extreme chemical weathering in the warm, wet tropics. Although they may be associated with lush tropical rain forests, these soils are unproductive when vegetation is removed. Moreover, when cleared of plants, these soils are subject to accelerated erosion and can be baked to bricklike hardness by the Sun.

Soil Erosion

Soils are just a tiny fraction of all Earth materials, yet they are a vital resource. Because soils are necessary for the growth of rooted plants, they are the very foundation of the human life-support system. Just as human ingenuity can increase the agricultural productivity of soils through fertilization and irrigation, soils can be damaged or destroyed by careless activities. Despite their basic role in providing food, fiber, and other basic materials, soils are among our most abused resources.

Perhaps this neglect and indifference has occurred because a substantial amount of soil seems to remain even where soil erosion is serious. Nevertheless, although the loss of fertile topsoil may not be obvious to the untrained eye, it is a growing problem as human activities expand and disturb more and more of Earth’s surface.

How Soil Is Eroded

Soil erosion is a natural process. It is part of the constant recycling of Earth materials that we call the rock cycle. Once soil forms, erosional forces, especially water and wind, move soil components from one place to another. Every time it rains, raindrops strike the land with surprising force. Each drop acts like a tiny bomb, blasting movable soil particles out of their positions in the soil mass. Then, water flowing across the surface carries away the removed soil particles. Because the soil is moved by thin sheets of water, this process is termed sheet erosion.

After a thin, unconfined sheet has flowed for a relatively short distance, threads of current typically develop, and tiny channels called rills begin to form. Still deeper cuts in the soil, known as gullies, are created as rills enlarge. When normal farm cultivation cannot eliminate the channels, we know the rills have grown large enough to be called gullies. Although most dislodged soil particles move only a short distance during each rainfall, substantial quantities eventually leave the fields and make their way downslope to a stream. Once in the stream channel, these soil particles, which can now be called sediment, are transported downstream and eventually deposited elsewhere.

Rates of Erosion

We know that soil erosion is the ultimate fate of practically all soils. In the past, erosion occurred at slower rates than it does today because more of the land surface was covered and protected by trees, plants, grasses, and other plants. However, human activities such as farming, logging, and construction, which remove or disrupt the natural vegetation, have greatly accelerated the rate of soil erosion. Without the stabilizing effect of plants, the soil is more easily swept away by the wind or carried downslope by sheet wash.

Natural rates of soil erosion vary greatly from one place to another and depend on soil characteristics as well as such factors as climate, topography, and type of vegetation. Over a broad area, erosion caused by surface runoff may be estimated by determining the sediment loads of the streams that drain the region.

When studies of this kind were made on a global scale, they indicated that prior to the appearance of humans, sediment transport by rivers to the ocean amounted to just over 9 billion metric tons per year (1 metric ton = 1000 kilograms). By contrast, the amount of material currently transported to the sea by rivers is about 24 billion metric tons per year, or more than two and a half times the earlier rate. Soil due to wind erosion. However, the removal of soil by wind is generally much less significant than erosion by flowing water except during periods of prolonged drought. When dry conditions prevail, strong winds can remove large quantities of soil from unprotected fields.
Sedimentation and Chemical Pollution

Another problem related to excessive soil erosion involves the deposition of sediment. Each year in the United States hundreds of millions of tons of eroded soil are deposited in lakes, reservoirs, and streams. The detrimental impact of this process can be significant. For example, as more and more sediment is deposited in a reservoir, the capacity of the reservoir is reduced, limiting its usefulness for flood control, water supply, and/or hydroelectric power generation. In addition, sedimentation in streams and other waterways can restrict navigation and lead to the need for costly dredging operations. In some cases soil particles are contaminated with pesticides used in farming. When these chemicals are introduced into a lake or reservoir, the quality of the water supply is threatened, and aquatic organisms may be endangered.

In addition to pesticides, nutrients found naturally in soils as well as those added by agricultural fertilizers make their way into streams and lakes, where they stimulate the growth of plants. Over a period of time, excessive nutrients accelerate the process by which plant growth leads to the depletion of oxygen and an early death of the lake. The availability of good soils is critical if the world’s rapidly growing population is to be fed. On every continent, soil loss is occurring because appropriate conservation measures are not being used. Although it is a recognized fact that soil erosion can never be completely eliminated, soil conservation programs can substantially reduce the loss of this basic resource.

Weathering and Ore Deposits

Weathering creates many important mineral deposits by concentrating minor amounts of metals that are scattered through unweathered rock into economically valuable concentrations. Such a transformation is often termed secondary enrichment and takes place in one of two ways. In one situation, chemical weathering coupled with downward-percolating water removes undesired materials from decomposing rock, leaving the desired elements enriched in the upper zones of the soil. The second way is basically the reverse of the first. That is, the desirable elements that are found in low concentrations near the surface are removed and carried to lower zones, where they are re-deposited and become more concentrated.

Weathering and Soils in Review

- External processes include (1) weathering—the disintegration and decomposition of rock at or near Earth’s surface; (2) mass wasting—the transfer of rock material downslope under the influence of gravity; and (3) erosion—the removal of material by a mobile agent, usually water, wind, or ice. They are called external processes because they occur at or near Earth’s surface and are powered by energy from the Sun. By contrast, internal processes, such as volcanism and mountain building, derive their energy from Earth’s interior.

- Mechanical weathering is the physical breaking up of rock into smaller pieces. Rocks can be broken into smaller fragments by frost wedging (where water works its way into cracks or voids in rock and upon freezing expands and enlarges the openings), salt crystal growth, unloading (expansion and breaking due to a great reduction in pressure when the overlying rock is eroded away), and biological activity (by humans, burrowing animals, plant roots, etc.).
Chemical weathering alters a rock’s chemistry, changing it into different substances. Water is by far the most important agent of chemical weathering. Oxygen dissolved in water will oxidize iron-rich minerals, while carbon dioxide (CO₂) dissolved in water forms carbonic acid, which attacks and alters rock. The chemical weathering of silicate minerals frequently produces (1) soluble products containing sodium, calcium, potassium, and magnesium ions, as well as silica in solution; (2) insoluble iron oxides, including limonite and hematite; and (3) clay minerals.

The rate at which rock weathers depends on such factors as (1) particle size—small pieces generally weather faster than large pieces; (2) mineral make-up—calcite readily dissolves in mildly acidic solutions, and silicate minerals that form first from magma are least resistant to chemical weathering; and (3) climatic factors, particularly temperature and moisture. Frequently, rocks exposed at Earth’s surface do not weather at the same rate. This differential weathering of rocks is influenced by such factors as mineral make-up and degree of jointing.

Soil—that portion of the regolith (the layer of rock and mineral fragments produced by weathering) that supports the growth of Bauxite forms in rainy tropical climates. When aluminum-rich source rocks are subjected to the intense and prolonged chemical weathering of the tropics, most of the common elements, including calcium, sodium, and potassium, are removed by leaching. Because aluminum is extremely insoluble, it becomes concentrated in the soil (as bauxite, a hydrated aluminum oxide). Thus, the formation of bauxite depends on climatic conditions in which chemical weathering and leaching are pronounced, plus, of course, the presence of aluminum-rich source rock.

In a similar manner, important deposits of nickel and cobalt develop from igneous rocks rich in silicate minerals such as olivine. There is significant concern regarding the mining of bauxite and other residual deposits because they tend to occur in environmentally sensitive areas of the tropics. Mining is preceded by the removal of tropical vegetation, thus destroying rainforest ecosystems. Moreover, the thin moisture-retaining layer of organic matter is also disturbed. When the soil dries out in the hot sun, as has been mentioned, it becomes brick like and loses its moisture retaining qualities. Such soil cannot be productively farmed nor can it support significant forest growth. The long-term consequences of bauxite mining are clearly of concern for developing countries in the tropics, where this important ore is mined.

Other Deposits
Many copper and silver deposits result when weathering processes concentrate metals that are dispersed through a low grade primary ore. Usually such enrichment occurs in deposits containing pyrite (FeS₂), the most common and widespread sulfide mineral. Pyrite is important because when it chemically weathers, sulfuric acid forms, which enables percolating waters to dissolve the ore metals. Once dissolved, the metals gradually migrate downward through the primary ore body until they are precipitated. Deposition takes place because of changes that occur in the chemistry of the solution when it reaches the groundwater zone (the zone beneath the surface where all pore spaces are filled with water). In this manner, the small percentage of dispersed metal can be removed from a large volume of rock and re-deposited as a higher-grade ore in a smaller volume of rock.

Plants—is a combination of mineral and organic matter, water, and air. About half of the total volume of a good-quality soil is a mixture of disintegrated and decomposed rock (mineral matter) and humus (the decayed remains of animal and plant life); the remaining half consists of pore spaces, where air and water circulate.
The most important factors that control soil formation are *parent material*, *time*, *climate*, *plants and animals*, and *topography*.

Soil-forming processes operate from the surface downward and produce zones or layers in the soil called *horizons*. From the surface downward, the soil horizons are respectively designated as *O* (largely organic matter), *A* (largely mineral matter), *E* (where the fine soil components and soluble materials have been removed by eluviation and leaching), *B* (subsoil, often referred to as the *zone of accumulation*), and *C* (partially altered parent material).

Together the *O* and *A* horizons make up what is commonly called the *topsoil*. In the United States, soils are classified using a system known as the *Soil Taxonomy*. It is based on physical and chemical properties of the soil profile and includes six hierarchical categories. The system is especially useful for agricultural and related land-use purposes.

Soil erosion is a natural process. It is part of the constant recycling of Earth materials that we call the *rock cycle*. Once in a stream channel, soil particles, which can now be called *sediment*, are transported downstream and eventually deposited. *Rates of soil erosion* vary from one place to another and depend on the soil’s characteristics as well as on such factors as climate, slope, and type of vegetation. Human activities have greatly accelerated the rate of soil erosion in many areas.

Weathering creates ore deposits by concentrating minor amounts of metals into economically valuable deposits. The process, often called *secondary enrichment*, is accomplished by either (1) removing undesirable materials and leaving the desired elements enriched in the upper zones of the soil or (2) removing and carrying the desirable elements to lower soil zones where they are redeposited and become more concentrated. *Bauxite*, the principal ore of aluminum, is one important ore created as a result of enrichment by weathering processes. In addition, many copper and silver deposits result when weathering processes concentrate metals that were formerly dispersed through low-grade primary ore.